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THE BROOKHAVEN NATIONAL LABORATORY'S MULTIPARTICLE SPECTROMETER DRIFT CHAMBER SYSTEM

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Abstract

A system of drift chambers is being built to replace the present spark chambers in the Brookhaven National Laboratory's Multiparticle Spectrometer. This system will handle a beam of ∿ 3 million particles per second and have a resolution of 200 μm. A summary of the status of the chambers and the custom integrated circuits is presented. The data acquisition system is described. Prototype chambers have been built and tested with results that are consistent with the expected chamber properties.

Introduction

We are presently building a system of drift chambers to replace the spark chambers now used in the Brookhaven National Laboratory's Multiparticle Spectrometer (MPS).[1] The drift chamber system will provide the MPS with significantly improved capabilit: about an order of magnitude increase in beam handl capability to ∿ 3 million particles per second and factor of ∿ 3 reduction in the spatial resolution / ∿ 200 μm. These capabilities are required if th MPS is to be used to study multibody final states p duced with very small cross section such as ch ed particle production. In addition, the high r capabilities of the new detectors will greatly i ar the efficiency of utilization of the MPS s beam time. We have chosen to use drift chambe h a very short drift distance (∿ 3 mm) becau y are the only detectors presently capable of spatial resolution, large area coverage, and ope n in a magnetic field and at high particle rate We are presently building a system of 6000 wir or testing, which later will be expanded to over 20 wires. In addition to providing the MPS with an mely sophisticated particle detection system, th roject will permit us to study the kinds of detec that will be required at ISABELLE. First we will a description of the MPS, then we will summar the design and status of the drift chamber modules , electronics programs which have been previously scribed.[2] We will then describe the data acquisit n system and finally the results of tests of prototype chambers.

Multiparticle Spectrometer (MPS)

Fig. 1 shows the configuration of the MPS for a proposed experiment to measure single and double ϕ production in π^- and K^-p interactions. The MPS magnet is a large "C" magnet with a field volume approximately 2 m wide by 5 m long by 1-1/4 m high and a vertical field of up to 10 KG. In addition to the main drift chamber modules that are the principle tracking detectors inside the magnet, there are several multiwire proportional chambers (TPX's and TPY's) that are used in the triggers. Not shown are the drift chamber modules that would surround the target in other experiments. Downstream of the magnet are two large Cerenkov counters, C6 and C7; two scintillation counter hodoscopes, H3 and H7; and a large drift chamber, E-II. C6, C7, H3 and H7 are used for

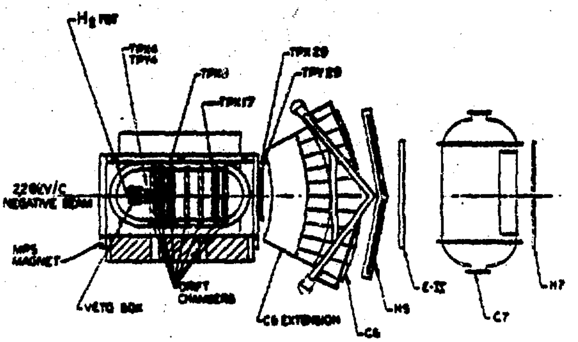

Figure 1 Layout of MPS for a proposed measurement of single and double ϕ production in π^- and K^-p interactions.

triggering, especially in conjunction with the RAM (a programmable 3-dimensional coincidence array).[3]

In addition to the equipment in the figure, the MPS facility has the electronics necessary to form triggers and record the data. Operation of the MPS is monitored using a PDP-KL10. The MPS can be used in either of two beams; a high energy unseparated beam and a medium energy separated beam.

Fig. 2 shows the results of a Monte Carlo study of the momentum and angular resolution that can be achieved using the drift chambers. The momentum resolution is shown in Fig. 2a. Fig. 2b shows the angular resolution for the angle projected onto the horizontal ("X") plane, at the first drift chamber module and as projected to the production vertex.

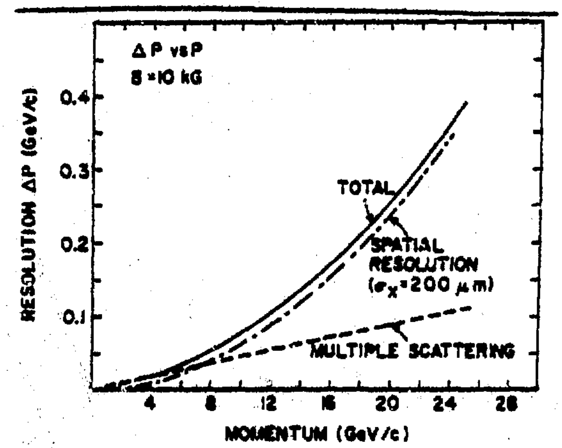

Figure 2a Monte Carlo calculation of the momentum resolution versus momentum for the drift chamber system.

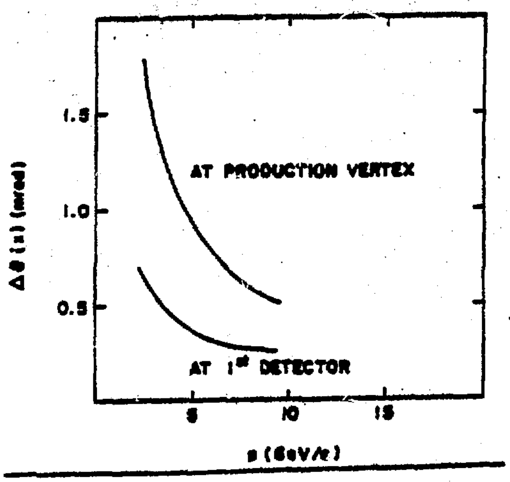

Figure 2b Monte Carlo calculation of the angular resolution versus momentum for the drift chamber system.

Drift Chamber Modules

The construction of main drift chamber modules has been discussed in an earlier publication[2] and is also shown in Fig. 3; in brief, there are three x-measuring chambers XXX' (X' shifted by the anode to field distance) to resolve the left-right ambiguity. This arrangement also permits us to calculate points and slopes within a module. One of two y-measuring chambers has cathode readout (U and V strips at ± 30° to the anode wires), which enables us to find three dimensional points in a single module. We are proceeding with the fabrication of these chambers according to the design and methods described elsewhere. We are, however, developing thick film hybrid networks with the intention of replacing the kapton based resistors and capacitors previously described,[2] to improve the dimensional accuracy of these circuits.

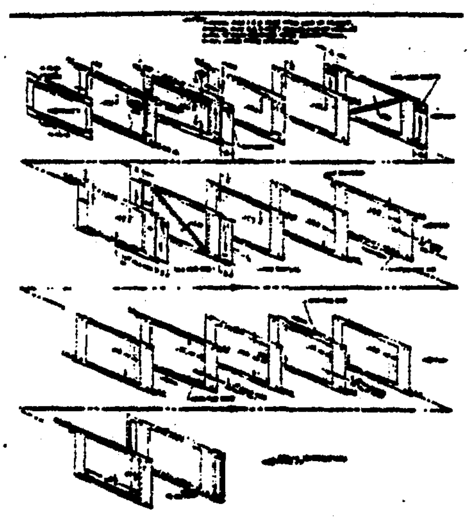

Figure 3 Expanded view of the drift chamber module.

We have assembled a full size Y chamber, which is undergoing tests, some results of which will be discussed. We expect to start assembling full modules by the end of the year and to test them in the spring.

In addition to the main drift chambers we will be building another system of drift chambers that will be on both sides of the target. At present a final design has not been arrived at, but we feel that the most favorable design is one in which the chambers have no frames at one end. Such a design would use small angle stereo to measure the second coordinate (Y).

Detector Electronics

We are developing three integrated circuits; an amplifier, a discriminator and a delay and time digitizer.[2] There are two versions of the four-channel amplifier, the first has a transresistance of 25KΩ, a dynamic range of 250 to 1 and a typical rise time of 6 ns, while the second has a transresistance of 12KΩ, a dynamic range of 1000 to 1 and a typical rise time of 4 ns. Prototypes of the first version have just been delivered. Tests of these chips, which include those on the full size Y chamber, indicate that the basic design is satisfactory although some changes will have to be made to fully satisfy the specifications. Delivery of the second version is not expected for several months. The four-channel discriminator has been described previously.[2] We are about to receive prototype units.

A CMOS-SOS shift register is used as the delay and time digitizer (Fig. 4).[2] With a 250 MHz clock speed, this circuit provides a delay of one microsecond and four nanosecond quantization. In actuality, due to a limitation in the speed capability of current technology, there are eight shift registers per channel operated by an eight phase clock driver; internal dividers are used to generate the eight clocks from four clock inputs. Other than providing the four clocks and ensuring that during readout of the data there be an even number of pulses of each external clock, each channel operates as if it is a single 256 bit shift register. It is possible to read out any number of bits per channel, subject to the above restrictions, up to the full 256. We are expecting delivery of prototypes shortly.

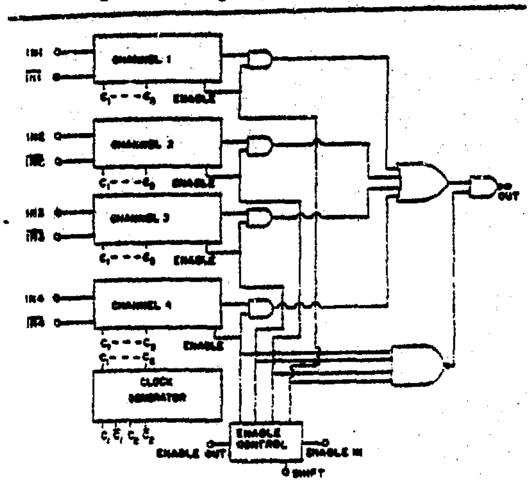

Figure 4 Functional diagram of the delay-digitizer integrated circuit.

In addition to the use of these integrated circuits in drift chambers they can be very useful separately. The second version of the amplifier was designed to also be used in linear applications such as dE/dx, where wide dynamic range is essential. Besides being useable as a general purpose discriminator, the discriminator can be used as a level translator to drive the shift register input. In addition to using the shift register as a delay line in such systems as multiwire proportional chambers, and flash ADC encoders, it can be used as a memory in a high speed logic analyser such as might be used in a fast bus system.

Data Acquisition System

Associated with each drift chamber module there will be a crate and data bus for the readout electronics (digitizers). In addition to the digitizers on each bus we plan to have three processors; an X point/slope, a Y point/slope and a three-dimensional point calculator. It was decided to use separate busses for each drift chamber module in order to permit the processors to access the data in the digitizers during the module readout cycle. Each module readout data bus will be connected to a second level bus structure that will in turn be interfaced to the data acquisition system for the MPS.

Operation of the readout is as follows. As previously described[2] the operation of the four channels on the shift register chip is controlled by a four bit long, on chip, enable-shift-register. There are three valid states of the enable register; one in all four bits, one in only one bit and zero's in all bits. During data taking there is a one in all four bits, which enables the clocks of all registers and disables the output stage, thus preventing contention problems. All zeros is the state of the enable register during most of the readout cycle, ensuring that the data is preserved and the output is disabled. A single one enables the clocks of the channel to be read out and enables the output stage.

There is a master clock control unit for the shift registers that stops and starts the high speed clock used during the reading-in of data. During readout it generates enables, enable shift pulses, the low speed readout clock, and control signals for the digitizers. This unit will also generate timing pulses for the test system, that will be on the second level data bus and which will continually monitor the drift chambers.

Initially, the master clock control will load all ones into all the enable registers and start the high speed clock. Approximately 1 μsec after the time of the event of interest, the clock control will stop the high speed clock, shift all zero's into the enable registers, shift a one into the enable bit of the first channel in a readout string, and start the readout clock (25 MHz). When 32 bits have been read out of the first channel, the readout clock will be stopped, an enable shift is generated, and the readout clock is restarted after a delay for settling. This is repeated for each channel in a given readout string, and when completed all one's are again shifted into the enable register and the fast clock restarted.

There are two digitizer boards each containing several digitizers; three X digitizers on one board and two Y, two U and two V digitizers on the other board. Because the direction of readout (see Fig. 3) cannot always be consistent with the MPS coordinate system and the U and V are read out in two parallel strings, it is not possible to use one common counter per board as the wire number counter if we are to encode the data consistent with the MPS coordinate system. Each board does have one common time bit counter. Each digitizer has a detector for a signal from the readout string data output; this detector can be gated to suppress data, such as fiducials and during pulser testing. A RAM is used to store the wire and time bit number of a signal. There are circuits to permit access to the contents of the RAM during the digitization cycle and transfer to a higher level.

When a channel is enabled, the time bit counter counts the readout clock and if a signal is detected the counter output is latched. After 32 slow clock pulses the readout clock is stopped and the content of the time bit latch and wire number counters are written into the RAM. After the write pulse the memory address counter is incremented, and the detector is reset.

There are actually two address counters; one used during digitization and transfer to the next higher level and another that controls transfer of data to the processors on the data bus during digitization. Transfer of data to a processor is permitted when the readout clock is running or when digitization is complete.

We plan to have three processors on each drift chamber data bus. An X point/slope unit will use the data from the three x planes and calculate best straight line fits. Since we have three planes, we can solve the left-right ambiguity by using the data from the first and third plane to predict the data in the middle plane. A comparison of these predictions with the data should eliminate most of the possible solutions; the best solution can be chosen using the data from all the modules.

With only two Y planes it is not possible to solve the problem of the up-down ambiguity for arbitrary angles, but if the tracks originate in the target we should be able to reduce the number of possible solutions. Three dimensional points will be calculated in the third processor using the data from the Y, U and V planes. Possible solutions require that the U and V segments be located symmetrically with respect to the Y wire and that all the corrected drift times be equal.

Sharing the second level data bus with the data box interface, there will be a processor that will monitor the operation of the drift chambers. This processor will analyze data from beam tracks that traverse the full system, with which we can monitor efficiency, drift velocity and timing. In addition, a pulser system will be used between beam spills and during setup. Using pulsers will allow us to find broken electrical connections, dead electronics and shift registers that have a defective phase.

Prototype Chamber Tests

We have, so far, built and tested a full size "Y" chamber, a two foot by four foot chamber with cathode strip readout and a small (eight inches square) set of three chambers (XXX').

Figure 5 shows the plateau curve for the full size Y chamber, obtained with a 70% Argon, 15% CO_2 and 15% C_2H_6 mixture. For different field wire high voltages, the results were similar: at least 500 V of full efficiency and stable operation. The drift time spectrum indicates that the drift velocity is saturated.

In the two by four chamber, which had ~ 3 mm drift distance and ~ 6 mm wide cathode strips, we measured the signals induced on the cathode strips. Approximately 13% of the signal on the anode was induced on the cathode strip nearest to the avalanches, 8% on the next nearest, and 2% on the third nearest.

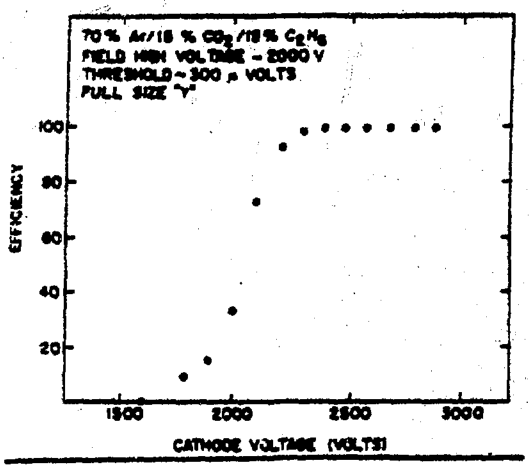

Figure 5 Plateau curve for the full size Y chamber obtained with a 70% Argon, 15% CO_2 and 15% C_2H_6 mixture.

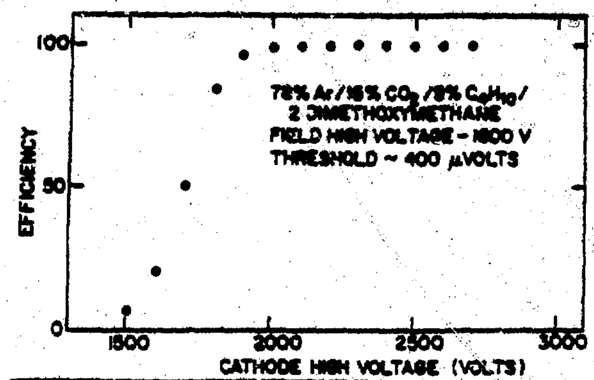

Figure 6a

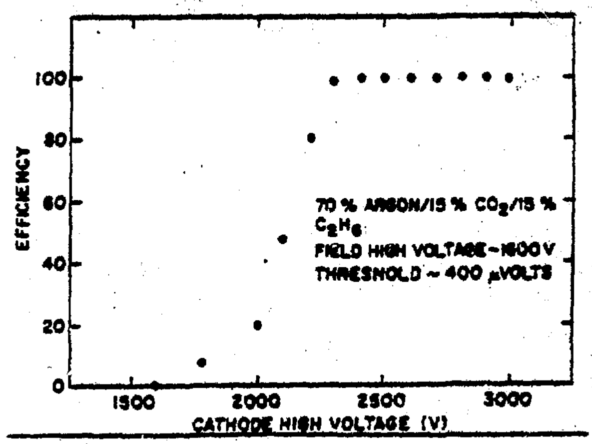

Figure 6b

Figure 6

Plateau curve for the small chamber, obtained with 78% Argon, 15% CO_2, 5% C_4H_{10} and 2% dimethoxymethane (a), and 70% Argon, 15% CO_2 and 15% C_2H_6 (b).

This result indicates that the data from the U and V planes will have very limited resolution which may require the use of U and V anode planes near the target. This chamber demonstrated the feasibility of using the kapton based resistor-capacitor networks in the chambers.

In the small chamber (drift distance is ~ 2.5 mm) we tried several gas mixtures looking for a mixture with which the chamber had a long plateau and linear drift time vs. distance relationship, and which was a simple-to-produce mixture while being safe to use. Two mixtures at this time are favored: 78% Argon, 15% CO_2, 5% C_4H_{10} and 2% dimethoxymethane and 70% Argon, 15% CO_2 and 15% C_2H_6. Plateau curves for these mixtures are shown in Fig. 6. They are similar with only a slight difference in the voltage of the knee. At other field wire voltages, plateaus of over 500 volts were measured.

A 24-channel shift register system was constructed of commercially available integrated circuits as a working prototype of our readout electronics now under development. With this prototype readout device, a more detailed study of the small drift chamber and its associated programs was done by operating it in a beam in the MPS. Two gas mixtures were used and the chamber was positioned at varying angles with respect to the beam. Some data was taken in a magnetic field.

We could not derive a precise value of the chamber resolution from our test because 1) there are no other devices in the beam with comparable resolution and 2) the procedure of internally comparing the three planes only gives an upper limit because of the broadening of the true peak due to false solutions. However, by comparing our results to distributions produced by Monte Carlo techniques, we can verify that the resolution is consistent with our expected value. Note that the problem of a substantial number of ambiguous solutions is peculiar to narrow gap drift chambers, because the relative fraction of tracks close to the anode is large.

The following technique was used to search for good point/slope combinations and to get an idea of the resolution. We form triplets consisting of a wire from each plane. There are two possible x coordinates that can be formed for each wire and its corresponding drift time. For each triplet of wire numbers and associated times, we generate the eight possible sets of x coordinates. The quantity DEV is defined to be

$$X_2 - (\frac{X_1 + X_3}{2})$$

where X_i is the position of the hit in the ith plane. The X's are defined in units of clock ticks. A plot of DEV is shown in Fig. 7 (for a normal incidence beam and the ethane mixture in the chamber). There is a clear central peak and two satellite peaks. The satellite peaks are due to those combinations for which the "wrong" choice is made for all 3 gaps and they are separated from the peak by a spacing equal to the maximum drift time. The central peak would have a finite width even for "perfect" resolution because of the quantization of the time clock. Fig. 8 shows a similar plot for Monte Carlo events.

Most of the contributions to Fig. 7 are from false combinations. Since the particles are normal to the chamber to within 10 mr, we can get a better idea of the values of DEV for correct combinations by only plotting DEV for combinations with slopes within ± 15 mr of zero. This cut removes a substantial fraction of the false combinations and the result is shown in Fig. 9. The satellite peaks disappear and leave the central peak with $\sigma \approx 1.1$ count. The Monte Carlo plot has a $\sigma \approx 0.8$ counts. A rough unfolding of the

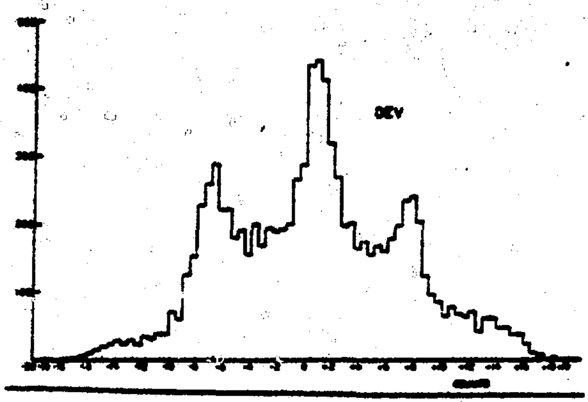

Figure 7 Number of combinations vs. DEV (the distance between a coordinate in the middle plane from the average of the coordinates in the first and third planes) for all possible combinations. The drift chamber is normal to the beam and contains the ethane gas mixture.

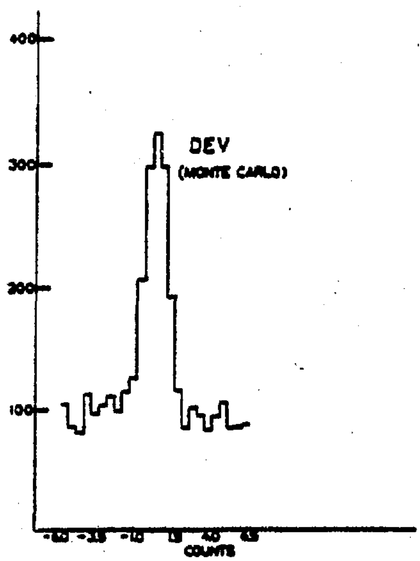

Figure 8 Number of combinations vs. DEV for Monte Carlo generated events.

quantization effect gives $\sigma \approx .8$ counts $\approx 240\mu$. Since this distribution contains contributions from 3 planes, the resolution from a single plane is estimated to be $\sigma_{Res} < 170\mu$. A further check on the resolution can be derived from the comparison of the track slope from the chamber and that given by the beam system. This distribution has $\sigma_{Slope} \approx 10$ mr which for this chamber geometry yields $\sigma_{Res} < 280\mu$.

Both of the above numbers should be regarded as upper limits because of the problems of resolving the ambiguities in a single chamber. One should note, however, that most of these ambiguities would not be a problem in using the chambers, because either 1) the ambiguous solutions differ by less than the resolution, or 2) the slopes are sufficiently different that extrapolation of the tracks to the next chamber will quickly eliminate false solutions.

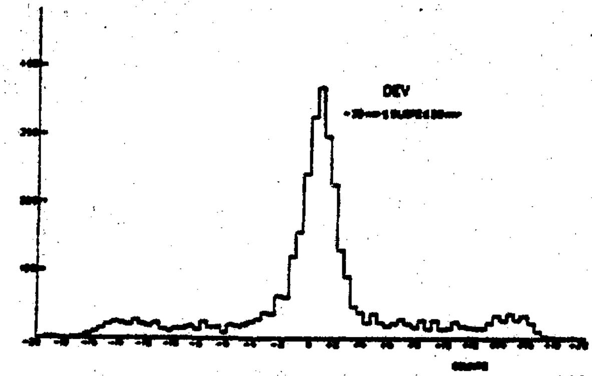

Figure 9 Number of combinations vs. DEV for only those combinations where the slope as defined by the coordinates in the first and third planes is between -35 mr and + 35 mr. The drift chamber is normal to the beam and contains the ethane gas mixture.

An acceptable coordinate combination for a possible track segment is defined as one for which the absolute value of DEV is less than some value DEVCUT. As a further confirmation of the resolution, we have found that for DEVCUT = 1.5 counts, 96% of the triplets have at least one acceptable combination.

Similar data was taken for the isobutane mixture. The DEV and slope distributions were somewhat wider ($\sigma \approx 1.45$ counts and 15 mr respectively): this may be due to the fact that the drift velocity seems to be higher for this gas, thus reducing the number of clock ticks for a given drift distance which in turn, will worsen both the apparent resolution due to quantization and the broadening due to false solutions. Thus, the ethane gas mixture is slightly favored.

We have taken data at angles of about 20 and 45 degrees. The 20 degree tracks look similar to those at zero degrees. The DEV distribution is broader with $\sigma \approx 1.7$ counts. Some of this broadening is the result of the fact that for angled tracks, the distance of closest approach of the track to the wire does not lie in the plane of the gap as our current algorithms assume. A naive calculation of this effect indicates it should be of the order of 0.5 counts at 20 degrees which is consistent with our findings. However, since for any coordinate combination the resulting track angle is known, this effect can be corrected in principle and we are working on such a program. When we apply a DEVCUT = 2 counts to this data, 93% of the triplets have at least one acceptable combination.

The 45 degree tracks introduce a new problem since for this narrow drift space geometry a large angle track can pass through the active volume of more than one wire in a gap. In addition, the problem of the distance of closest approach being out of the plane of the gap is more critical. The first problem is manageable because it turns out that there can be at most two adjacent wires struck with drift times that are less than or equal to the maximum expected drift time in a gap. The second problem is difficult to study in a single set of gaps and will be investigated in a test run with three sets of modules that is scheduled for Spring 1980.

The measurement in the magnetic field was hampered by statistics and some electronic problems. We can set an upper limit $\sigma_{Res} < 2$ counts, where some of the resolution is due to the fact that the tracks are bent in the magnetic field and are not perpendicular to the chamber. The measured angular resolution of $\sigma \approx 30$ mr is consistent with the above limits. An indication of the continuing overall quality of the detector is that setting DEVCUT at 2.0 counts, about 95% of the triplets have at least one acceptable combination.

Acknowledgements

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